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Constraints on top quark flavor changing neutral currents using diphoton events at the LHC

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Abstract

In this paper we show that the diphoton mass spectrum in proton–proton collisions at the LHC is sensitive to the top quark flavor changing neutral current in the vertices of $tu\gamma$ and $tc\gamma$. The diphoton mass spectrum measured by the CMS experiment at the LHC at a center-of-mass energy of 8 TeV and an integrated luminosity of 19.5 fb^{-1} is used as an example to set limits on these FCNC couplings. It is also shown that the angular distribution of the diphotons is sensitive to anomalous $tu\gamma$ and $tc\gamma$ couplings and it is a powerful tool to probe any value of the branching fraction of top quark rare decay to an up-type quark plus a photon down to the order of 10^{-4}.

1. Introduction

The top quark with a mass of 173.34 ± 0.75 GeV [1] is the heaviest particle of the Standard Model (SM). With such a mass, the top quark has the largest Yukawa coupling to the Higgs boson and therefore measurement of its properties would provide a promising way to probe the electroweak symmetry breaking mechanism and new physics beyond the SM. New physics can show up either through direct production of new particles or indirectly via higher order effects. Observing indirect evidences is important as it provides hints to look for new physics before direct

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discovery. In the Standard Model (SM), the branching fractions of top quark rare decays $t \to qV$, with $q = u, c$ and $V = \gamma, Z, g$, are at the order of 10^{-14}–10^{-12} [2]. Such branching fractions are extremely small and are out of the ability of the current and future collider experiments to be measured. Within the SM, such Flavor Changing Neutral Current (FCNC) transitions only occur at loop level and are strongly suppressed due to the Glashow–Iliopoulos–Maiani (GIM) mechanism [3]. On the other hand, it has been shown that several extensions of the SM are able to relax the GIM suppression of the top quark FCNC transitions due to additional loop diagrams mediated by new particles. Models, such as supersymmetry, two Higgs doublet models, predict significant enhancements for the FCNC top quark rare decays [4–18]. As a result, the observation of any excess for these rare decays would be indicative of indirect effects of new physics. Many studies on searches for the top quark FCNC and other anomalous couplings have been already done [19–36].

In this paper, a direct search for the top quark FCNC interactions in the vertex of $tq\gamma$ is discussed. Such interactions can be described in a model-independent way using the effective Lagrangian approach, which has the following form [37]:

$$\mathcal{L}_{\rm FCNC} = -eQ_t \sum_{q=u,c} \kappa_{tq\gamma}\bar{q}(\lambda^v_{tq\gamma} + \lambda^a_{tq\gamma}\gamma_5)\frac{i\sigma_{\mu\nu}q^\nu}{\Lambda} t A^\mu + h.c., \tag{1}$$

where the electric charges of the electron and top quark are denoted by e and eQ_t, respectively and q^ν is the four momentum of the involved photon, Λ is the cutoff of the effective theory, which is conventionally assumed to be equal to the top quark mass, unless we mention. In the FCNC Lagrangian in Eq. (1), $\sigma_{\mu\nu} = \frac{1}{2}[\gamma_\mu, \gamma_\nu]$ and the anomalous couplings strength is denoted by $\kappa_{tq\gamma}$. Throughout this paper, no specific chirality is assumed for the $tq\gamma$ FCNC couplings, i.e. $\lambda^v_{tq\gamma} = 1$ and $\lambda^a_{tq\gamma} = 0$. Within the SM framework, the values of $\kappa_{tq\gamma}$, $q = u, c$, vanish at tree level.

The leading order (LO) partial width of the top quark FCNC decay $t \to q\gamma$, neglecting the masses of the up and charm quarks, has the following form [38]:

$$\Gamma(t \to q\gamma) = \frac{\alpha}{2} Q_t^2 m_t |\kappa_{tq\gamma}|^2, \tag{2}$$

and the LO width of $t \to bW^+$ can be written as [38,39]:

$$\Gamma(t \to bW^+) = \frac{\alpha |V_{tb}|^2}{16 s_W^2} \frac{m_t^3}{m_W^2}\left(1 - \frac{3m_W^4}{m_t^4} + \frac{2m_W^6}{m_t^6}\right), \tag{3}$$

where α and V_{tb} are the fine structure constant and the CKM matrix element, respectively. The sine of the Weinberg angle is denoted by s_W and m_t, m_W are the top quark and W boson mass, respectively. The branching fraction of $t \to q\gamma$ is estimated as the ratio of $\Gamma(t \to q\gamma)$ to the width of $t \to bW^+$ which takes the following form [38]:

$$Br(t \to q\gamma) = 0.2058 \times |\kappa_{tq\gamma}|^2. \tag{4}$$

To obtain the above branching fraction, we set $m_t = 172.5$ GeV, $\alpha = 1/128.92$, $m_W = 80.419$ GeV and $s_W^2 = 0.234$ in $t \to q\gamma$ and $t \to bW^+$ widths.

The $tu\gamma$ and $tc\gamma$ FCNC couplings have been studied in different experiments with no observation of any excess above the SM expectation up to now. In $p\bar{p}$ collisions at the Tevatron, the CDF experiment has set the following upper bounds on the branching fraction at the 95% confidence level (CL) [40]:

$$Br(t \to q\gamma) < 3.2 \times 10^{-2}\ ,\ \text{with } q = u, c. \tag{5}$$